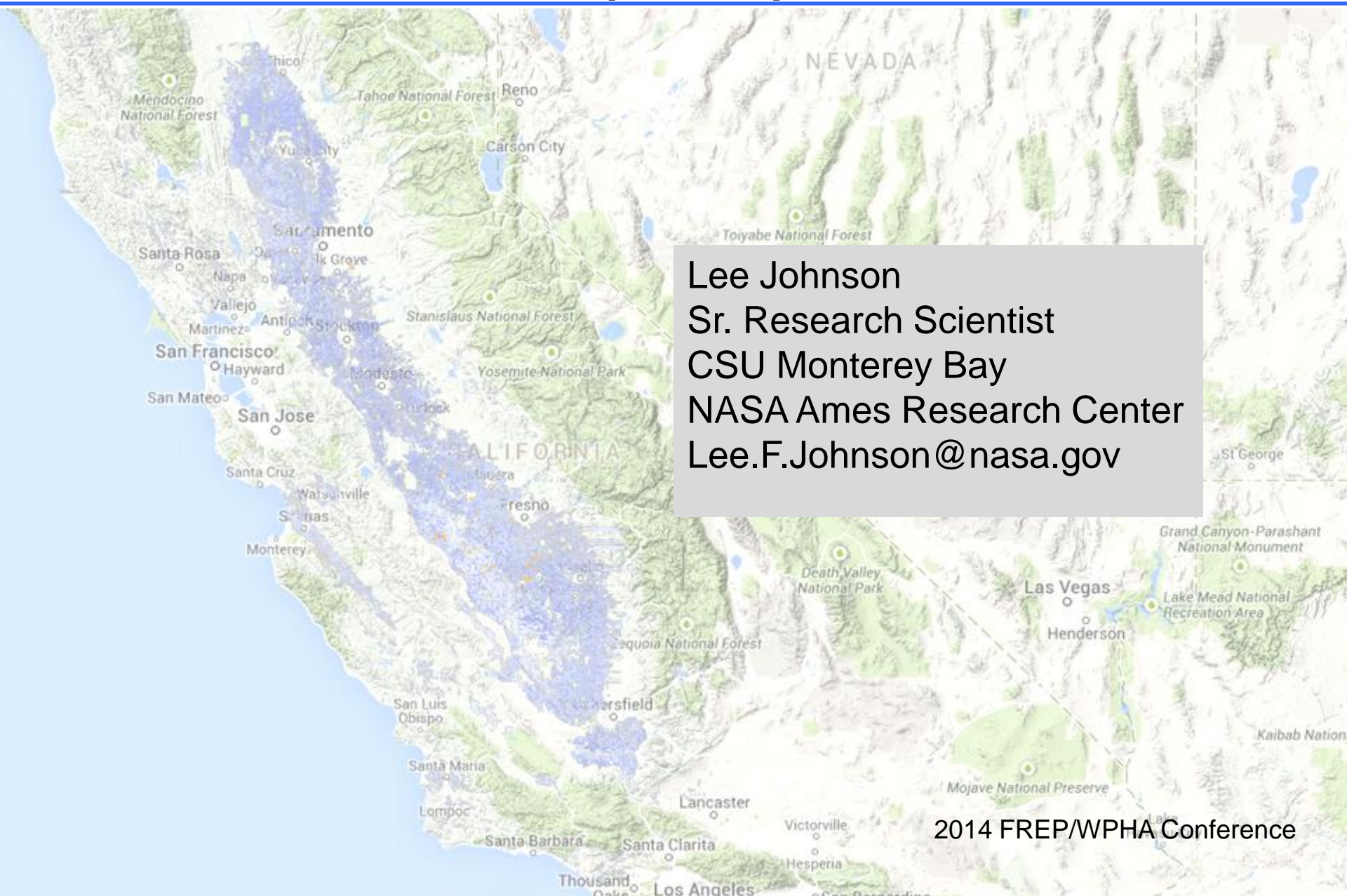


Remote Sensing of Crop Development and Evapotranspiration



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A satellite map of a coastal region, likely California, showing land in green and brown and water in blue. The map is partially obscured by a blue horizontal bar at the top.

Outline

- Intro/context
- Supporting technologies
- Satellite-based mapping in California
- Example applications

Water resource management challenges

- Competing demands
- Drought impacts
- Water quality and impaired water bodies
- Aging water conveyance infrastructure
- Groundwater overdraft
- Population growth and climate change
- Interaction w/ nitrate mgt

Improving irrigation management

- Agronomic
- Engineering
- Institutional
- Managerial; eg, ET-based scheduling

Howell (2001)

Definitions

- **Evapotranspiration (ET):** Water lost to the atmosphere from combined processes of evaporation from soil/plant surfaces, and transpiration by plant tissues.
- **Reference evapotranspiration (ET_o):** ET from a well-watered reference crop (grass in Calif.)
- **Crop ET (ET_c):** ET from an agricultural crop (basal vs. net)
- **Crop coefficient (K_c):** A unitless coefficient used to convert ET_o to ET_c for a specific crop.
- **Fractional cover:** proportion of field covered by green crop (vs. bare soil) as viewed from above

Basal conditions ($ET \approx$ potential transpiration)

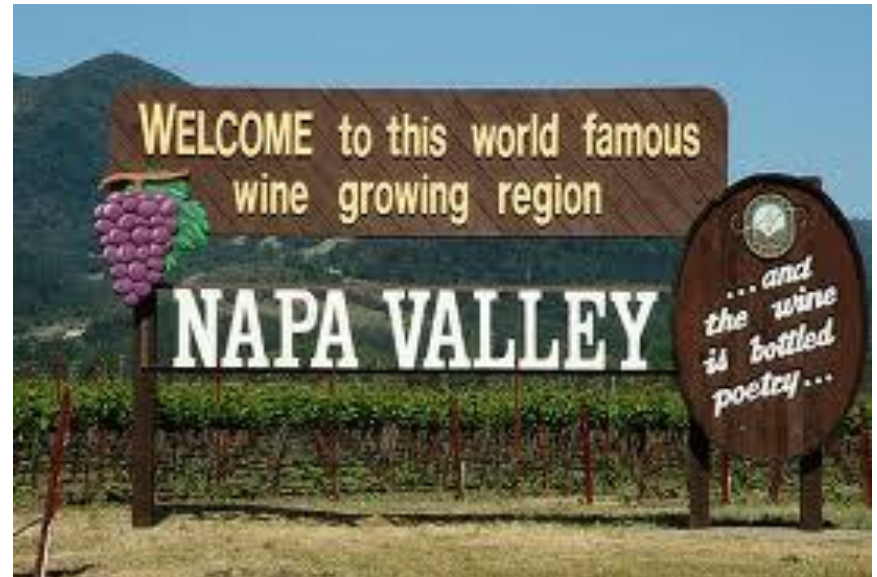


Well-watered crop, on drip

Non-basal conditions



Bare-soil evaporation



Deficit irrigation (water stress)

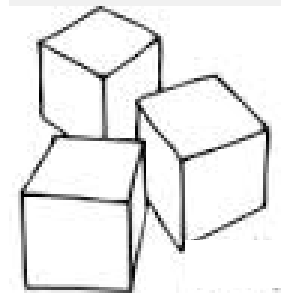
Remote sensing of crop ET

2 main approaches:

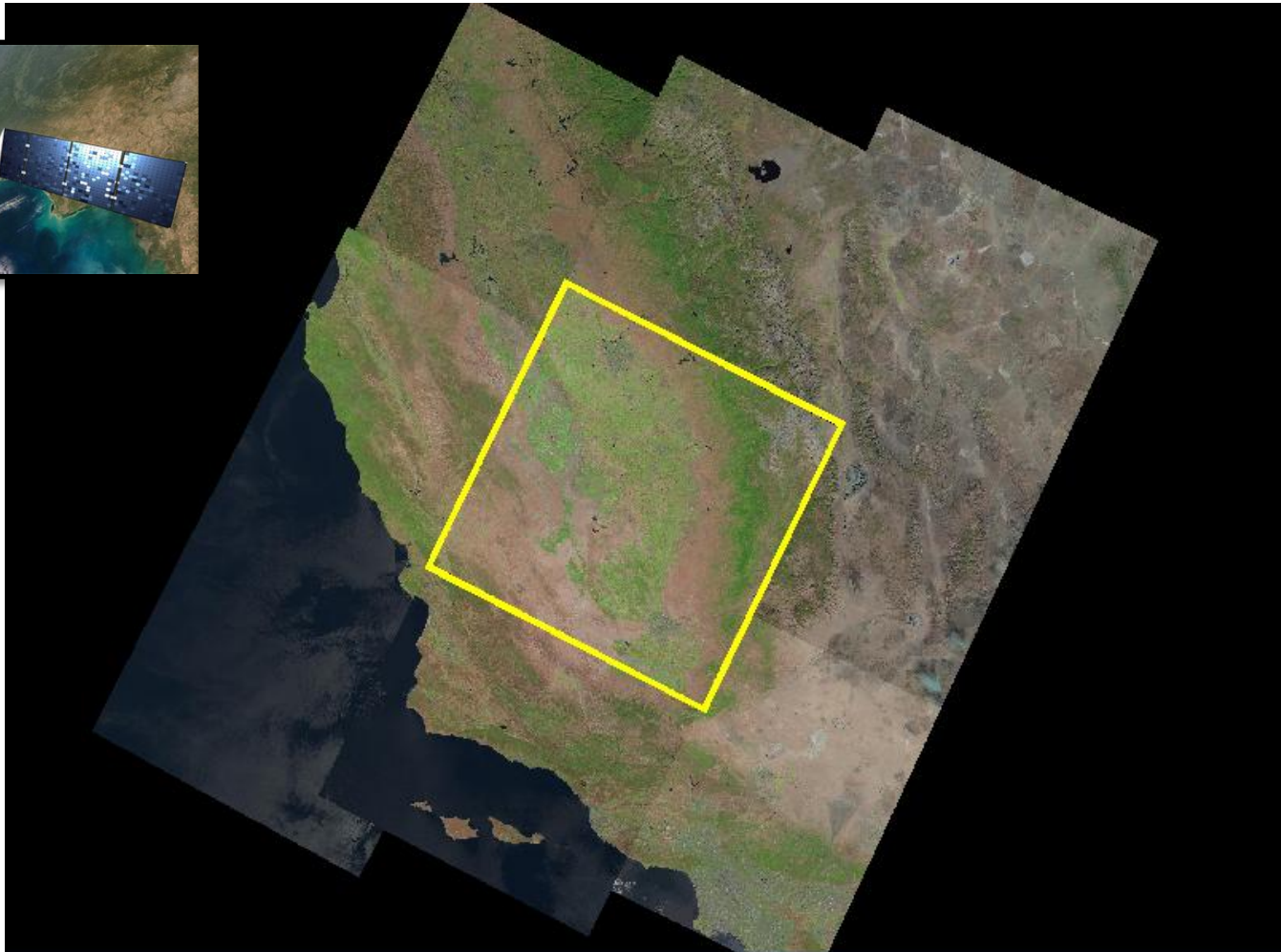
- Vegetation index methods (e.g., SIMS)
 - Primarily uses two spectral bands: red & near-infrared
 - Basal conditions (potential transpiration)
 - Optional post-processing via soil water balance model
- Surface energy balance methods (SEBAL, METRIC)
 - Uses all spectral bands, including thermal infrared
 - Accounts for crop stress and soil evaporation
 - Automation a continuing challenge

Building blocks

- Landsat system & associated research
- Prior ag-engineering/irrigation research
- CIMIS data availability

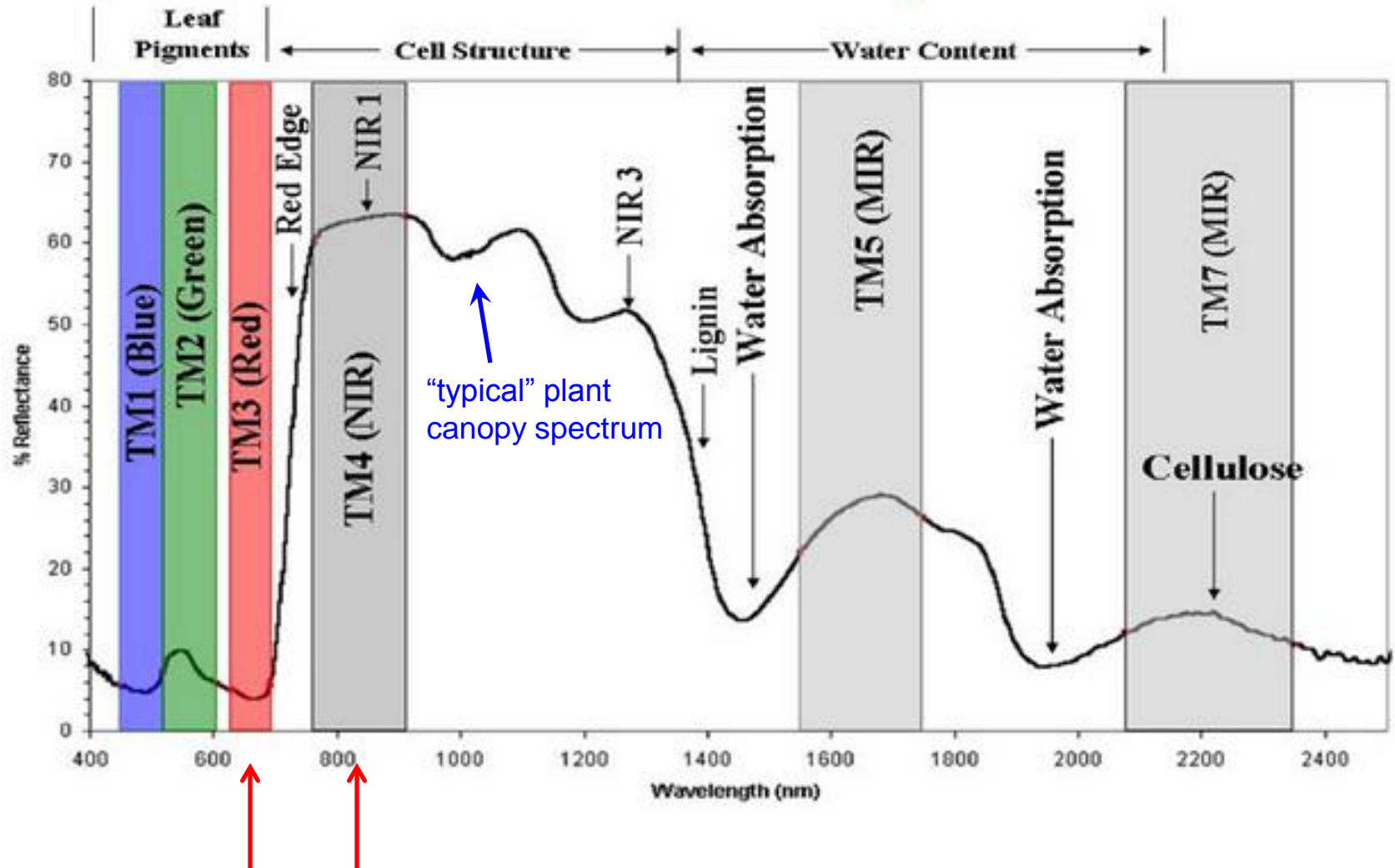


Landsat 7, 8



$\frac{1}{4}$ acre resolution, overpass every 8 days

Landsat spectral bands

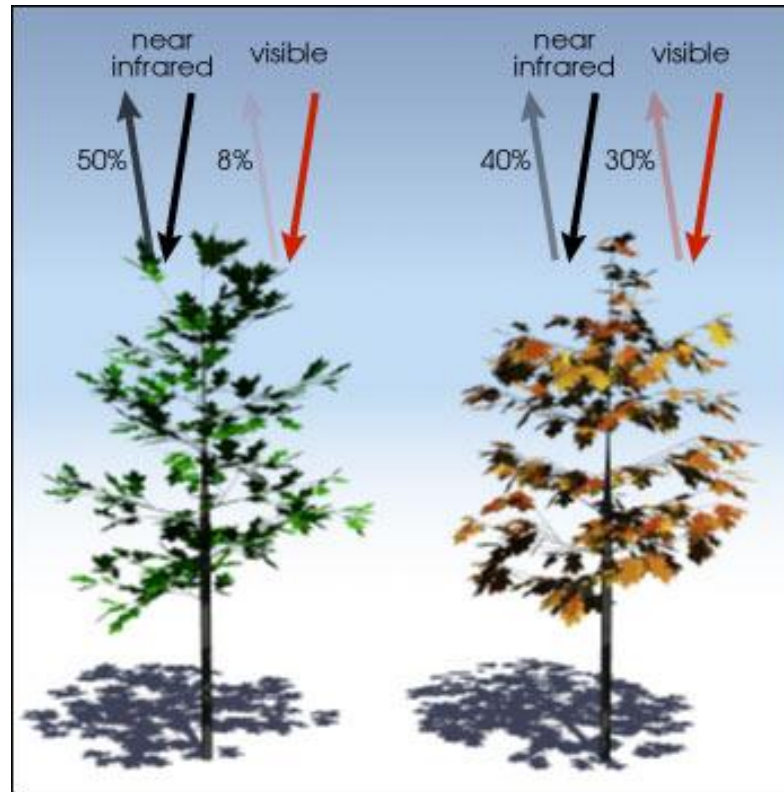


Normalized Difference Vegetation Index (NDVI)

Canopy Reflectance

More green cover:

Higher NIR,
Lower red



Less green cover:

Lower NIR,
Higher red

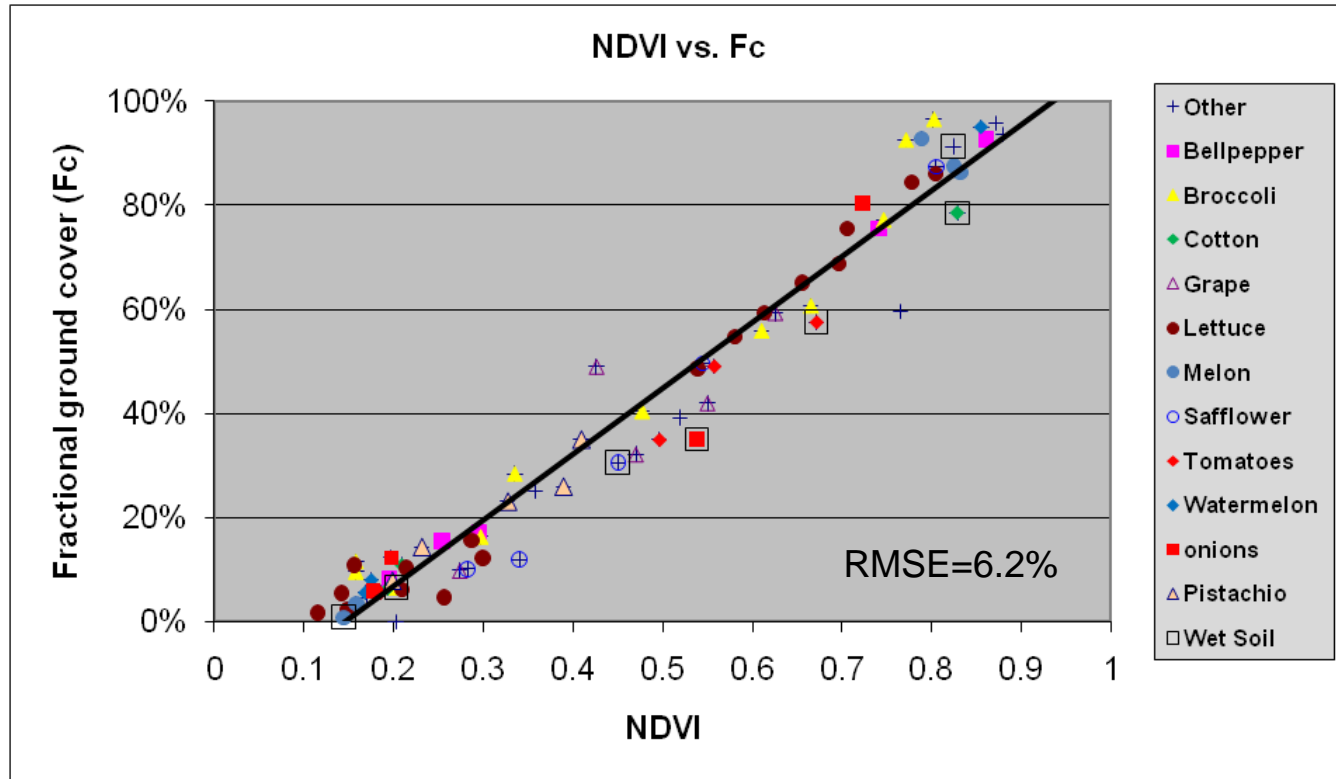
$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$$

$$\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Higher NDVI 

 Lower NDVI

NDVI vs. crop development



-Led by USDA/ARS

-Good relationship NDVI vs. green crop cover shown for several Calif. crops

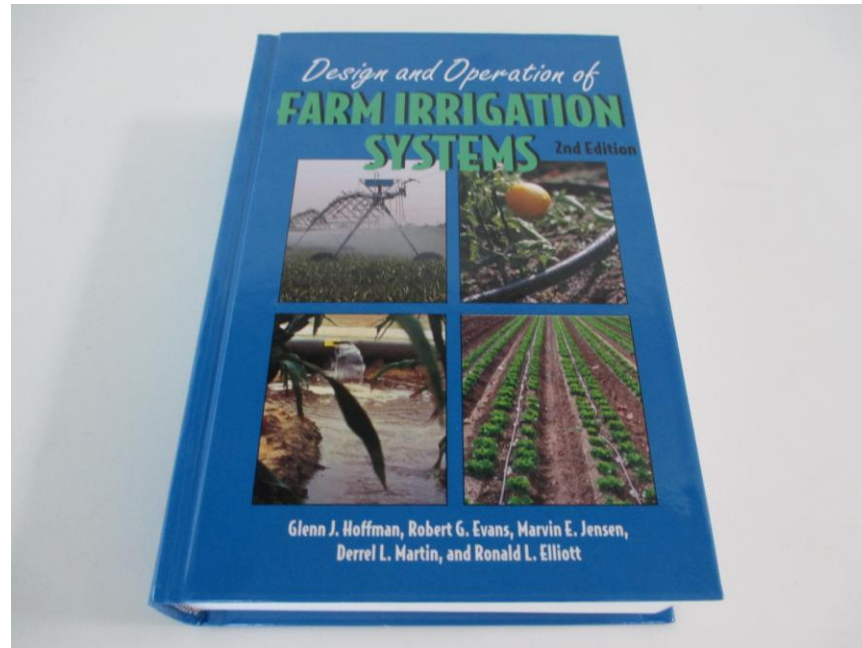
-Additional testing ongoing in collaboration with UC Cooperative Extension

ETc drivers

- Crop fractional cover (net radiation)
- Crop height (aerodynamic resistance)
- Stomatal control (canopy resistance)
- Evaporation from exposed soil

FAO-56 (Crop Evapotranspiration: Guidelines for
Computing Crop Water Requirements)

Basal crop coefficient (Kcb)



(Amer. Soc. Agric. Bio. Engrs.)

- Fractional cover (and crop height) as basis for crop coeff. estimation
- “Density coefficient” approach

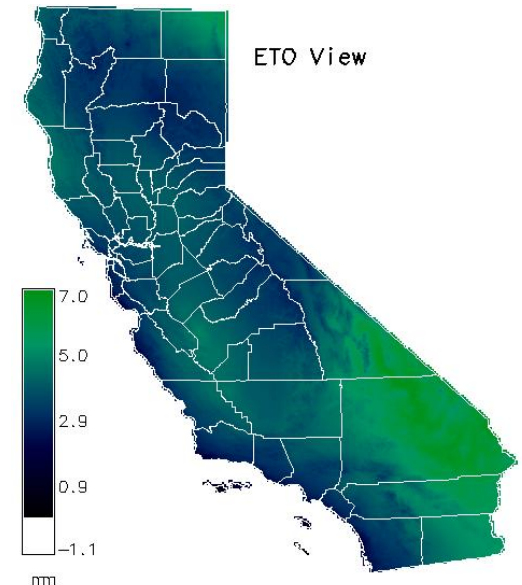
CIMIS reference evapotranspiration

California Irrigation Management Information System (CIMIS)

- Calif. Dept. Water Resources
- Operating since 1982
- Statewide network archives daily measurements of ETo
- **Spatial CIMIS** 2km statewide grid, daily
 - GOES geostationary satellite used to modify clear-sky radiation estimates
 - Partnership between CDWR & UC Davis (Hart et al., 2009)

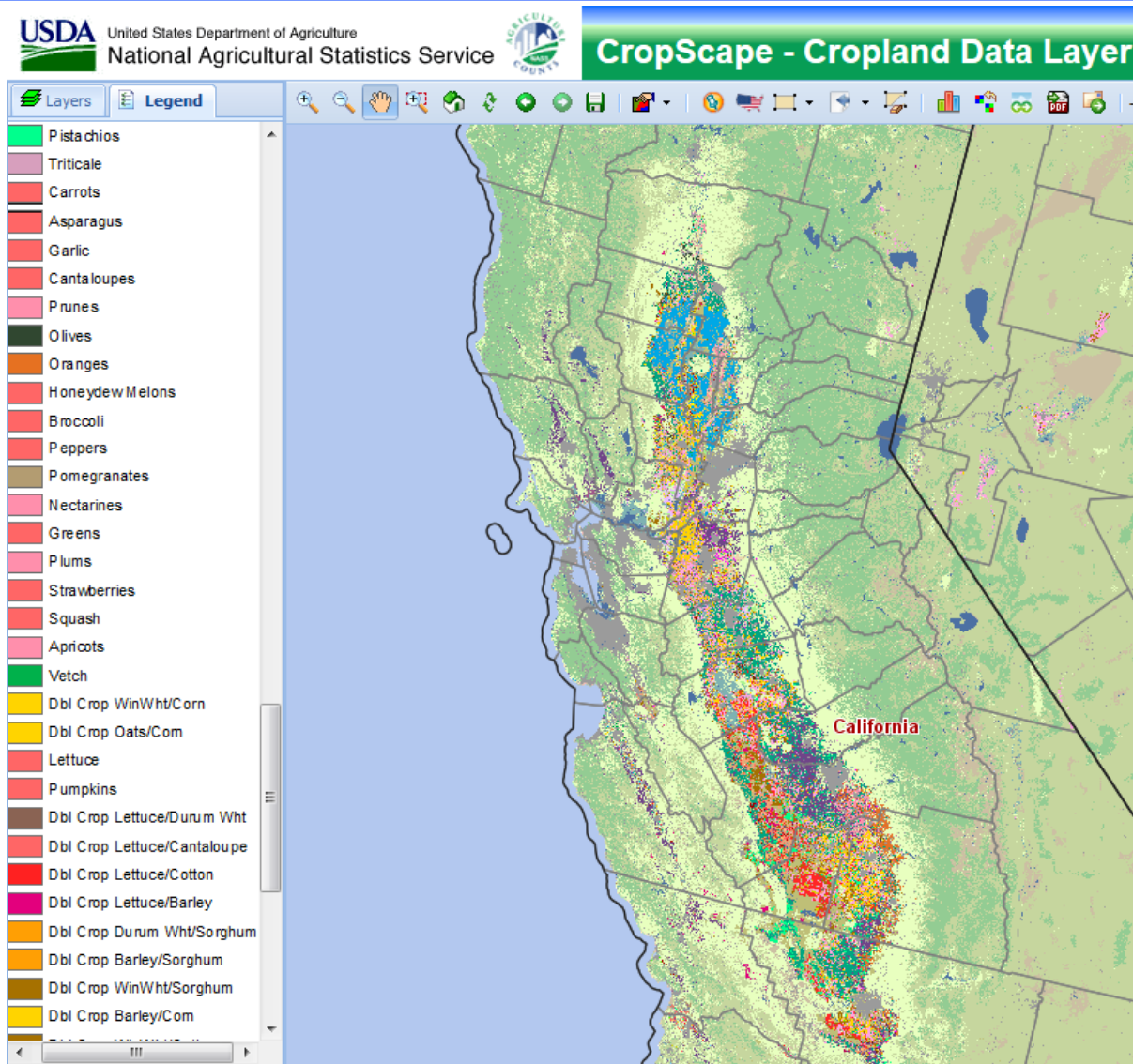


Photo credit: DWR CIMIS



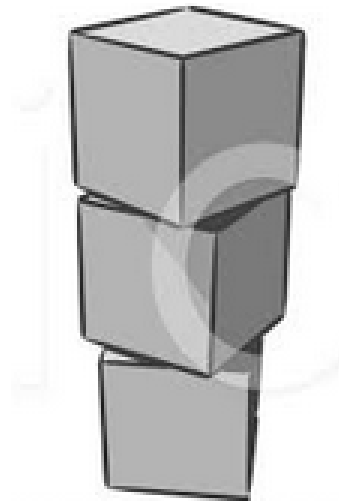
Spatial CIMIS ETo 13-Oct-2014

CDL (crop type)

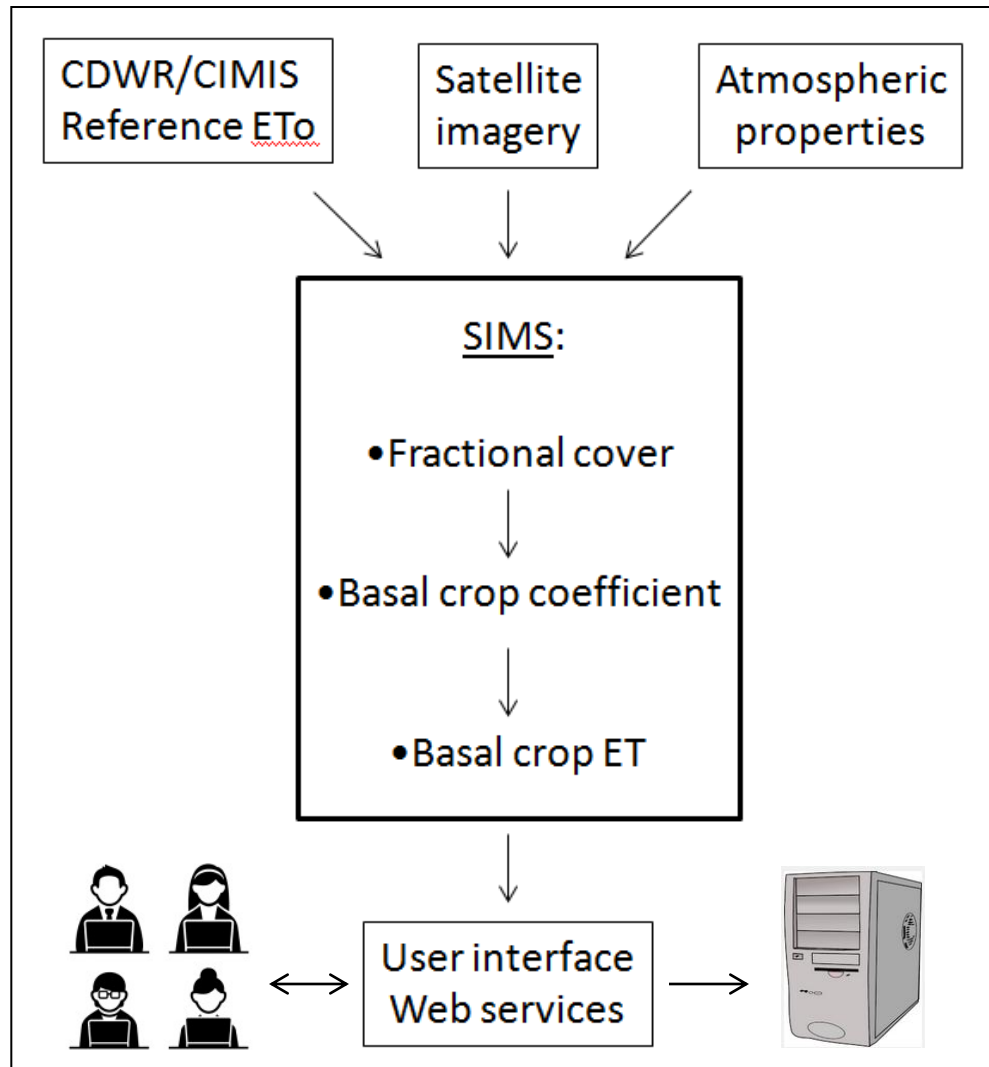


- Landsat + other satellite imagery informed by Farm Service Agency ground data
- >100 crop classes
- Annual update
- Retrospective (year-end)

SIMS



SIMS flowchart



SIMS NDVI



TOPS Satellite Irrigation Management Support

Username:

Password:

Login

Go to:

Search

[About](#) [Help](#)

Select Date: 2014-09-13



Shown:
Basal ETc and NDVI for 13-Sep-2014

SIMS Data Layers

- ☒ ETcb
2014-09-13
- ☐ Crop coefficient (Kcb)
2014-09-06 to 2014-09-13
- ☐ Fractional Cover (FC)
2014-09-06 to 2014-09-13
- ☒ NDVI Landsat and MODIS
2014-09-06 to 2014-09-13
- ☐ NDVI Landsat only
2014-09-06 to 2014-09-13

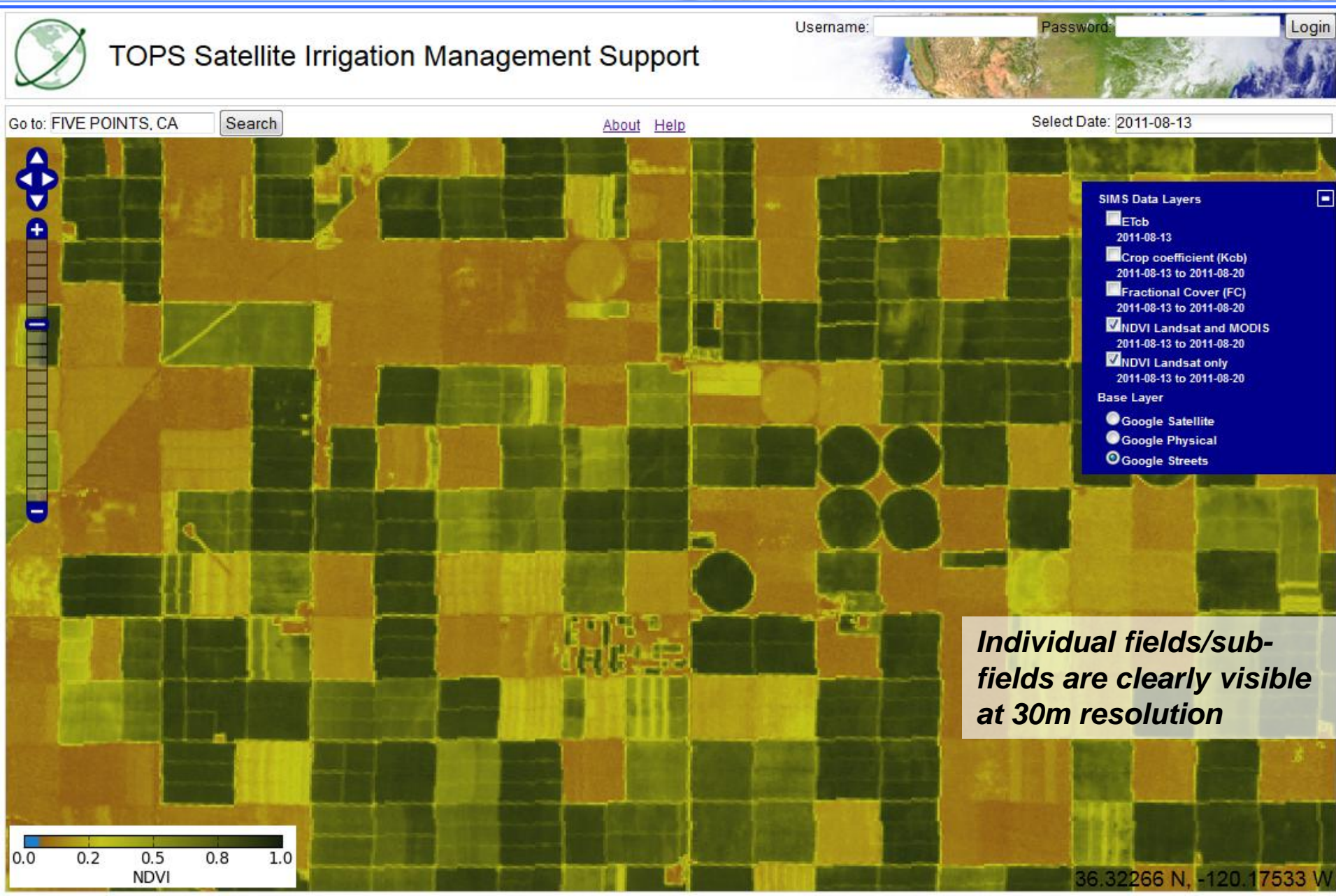
Base Layer

- ☐ Google Satellite
- ☒ Google Physical
- ☐ Google Streets

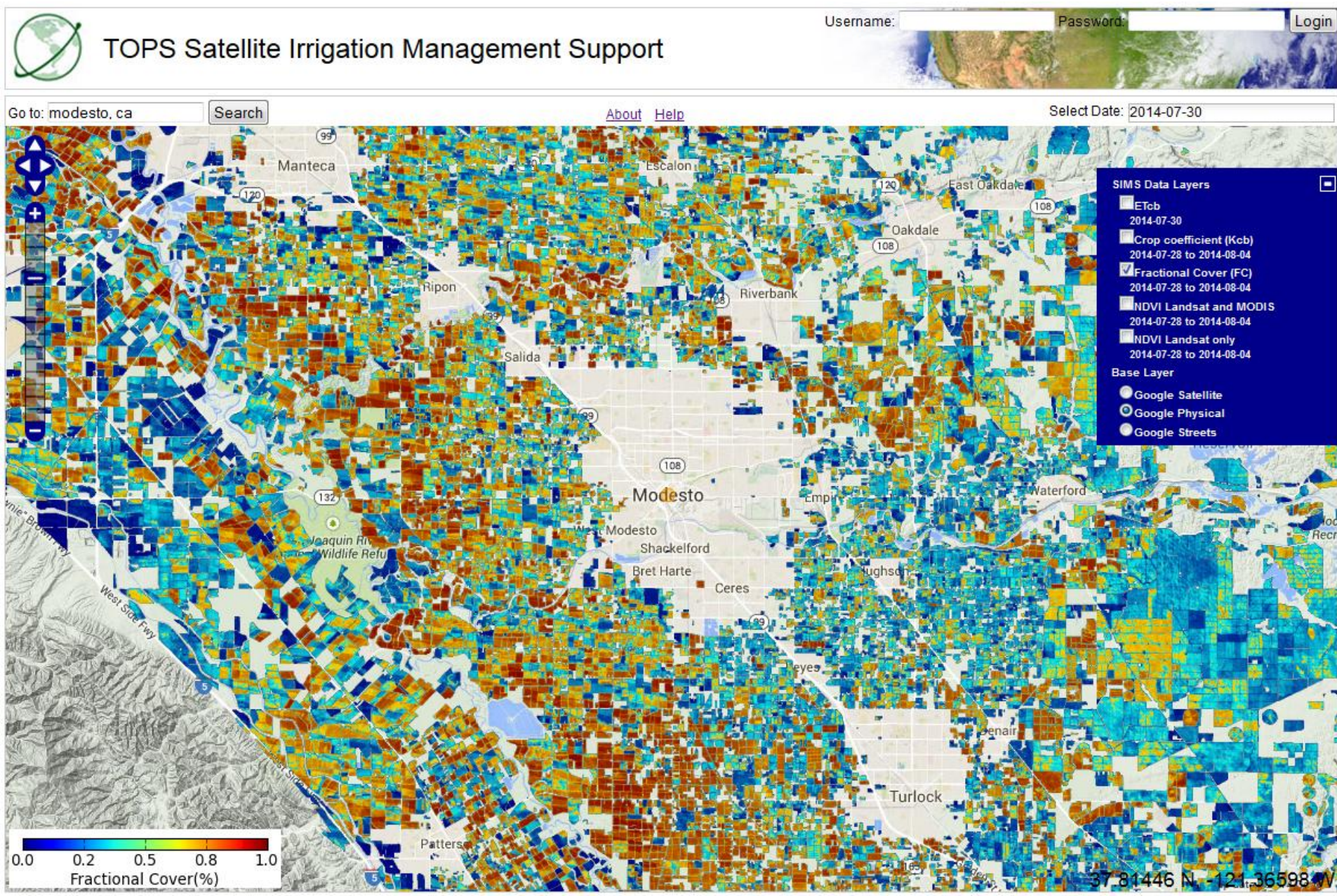


39.17192 N, -126.14735 W

NDVI close-up



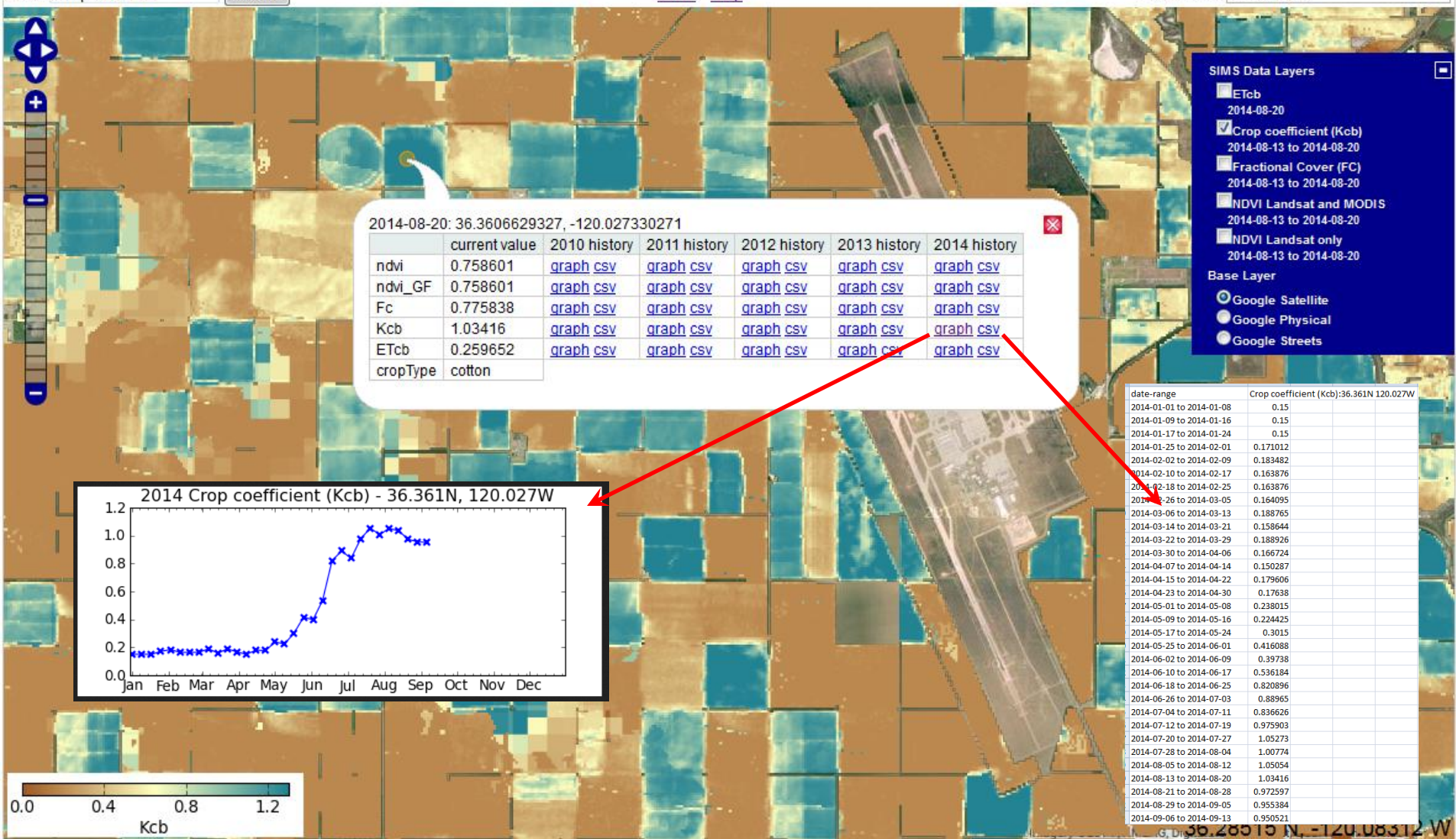
Crop fractional green cover



Crop coefficient (basal)



Go to: five points, ca [About](#) [Help](#) Select Date: 2014-08-20



2014-08-20: 36.3606629327, -120.027330271						
	current value	2010 history	2011 history	2012 history	2013 history	2014 history
ndvi	0.758601	graph csv	graph csv	graph csv	graph csv	graph csv
ndvi_GF	0.758601	graph csv	graph csv	graph csv	graph csv	graph csv
Fc	0.775838	graph csv	graph csv	graph csv	graph csv	graph csv
Kcb	1.03416	graph csv	graph csv	graph csv	graph csv	graph csv
ETcb	0.259652	graph csv	graph csv	graph csv	graph csv	graph csv
cropType	cotton					

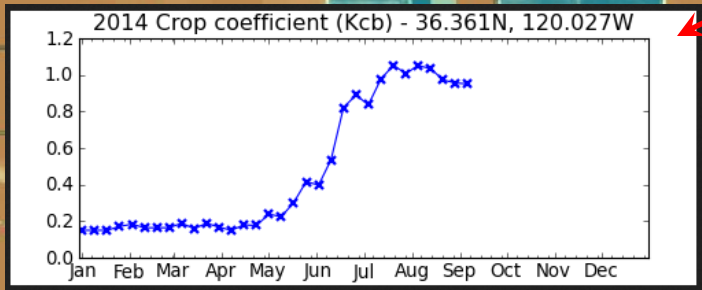
SIMS Data Layers

- ☐ ETcb
- ☐ 2014-08-20
- ☒ Crop coefficient (Kcb)
- ☐ 2014-08-13 to 2014-08-20
- ☐ Fractional Cover (FC)
- ☐ 2014-08-13 to 2014-08-20
- ☐ NDVI Landsat and MODIS
- ☐ 2014-08-13 to 2014-08-20
- ☐ NDVI Landsat only
- ☐ 2014-08-13 to 2014-08-20

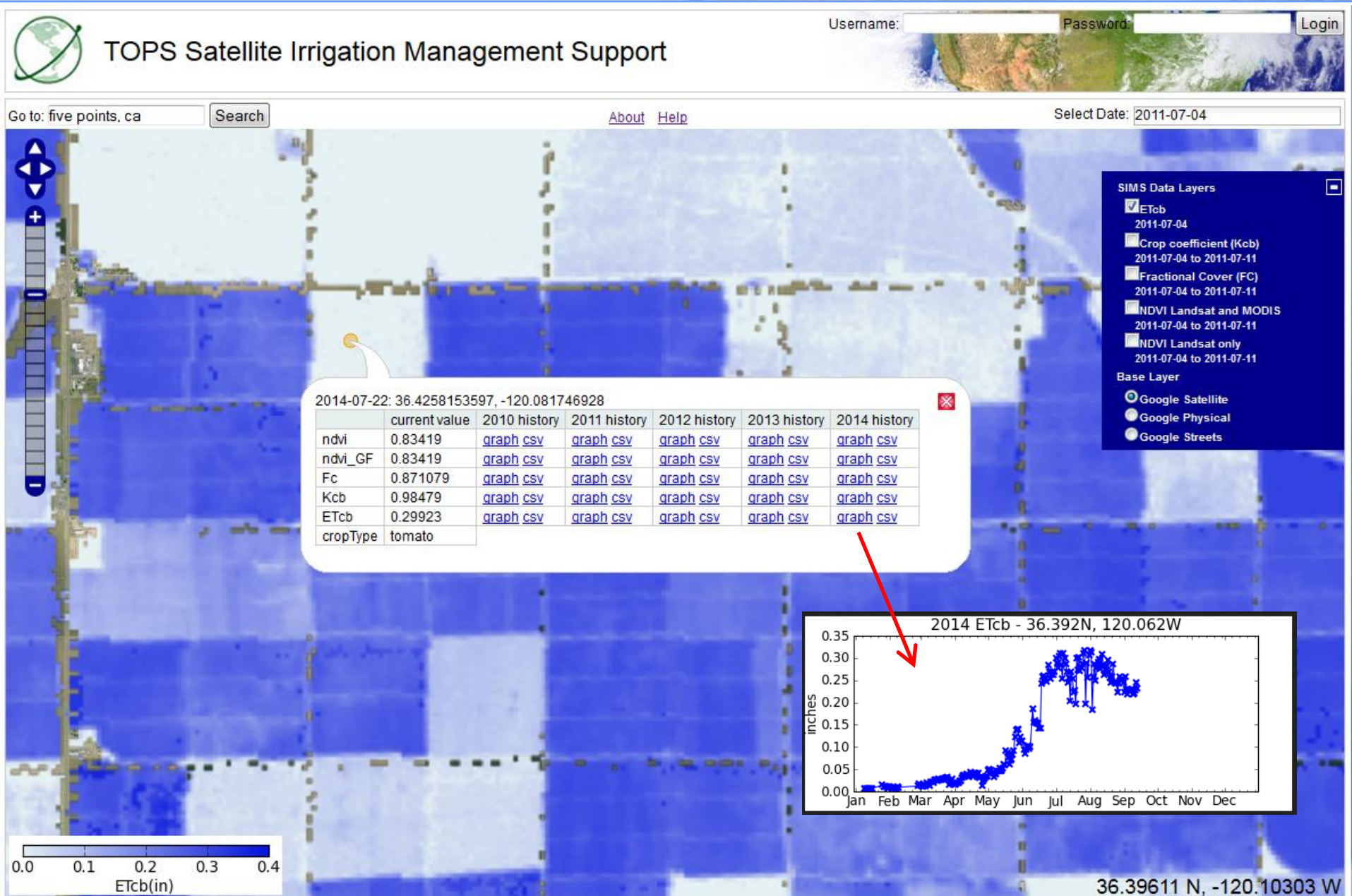
Base Layer

- ☒ Google Satellite
- ☐ Google Physical
- ☐ Google Streets

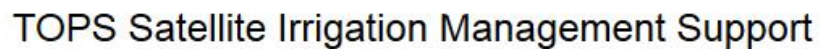
date-range	Crop coefficient (Kcb):36.361N 120.027W
2014-01-01 to 2014-01-08	0.15
2014-01-09 to 2014-01-16	0.15
2014-01-17 to 2014-01-24	0.15
2014-01-25 to 2014-02-01	0.171012
2014-02-02 to 2014-02-09	0.183482
2014-02-10 to 2014-02-17	0.163876
2014-02-18 to 2014-02-25	0.163876
2014-02-26 to 2014-03-05	0.164095
2014-03-06 to 2014-03-13	0.188765
2014-03-14 to 2014-03-21	0.158644
2014-03-22 to 2014-03-29	0.188926
2014-03-30 to 2014-04-06	0.166724
2014-04-07 to 2014-04-14	0.150287
2014-04-15 to 2014-04-22	0.179606
2014-04-23 to 2014-04-30	0.17638
2014-05-01 to 2014-05-08	0.238015
2014-05-09 to 2014-05-16	0.224425
2014-05-17 to 2014-05-24	0.3015
2014-05-25 to 2014-06-01	0.416088
2014-06-02 to 2014-06-09	0.39738
2014-06-10 to 2014-06-17	0.536184
2014-06-18 to 2014-06-25	0.820896
2014-06-26 to 2014-07-03	0.88965
2014-07-04 to 2014-07-11	0.836626
2014-07-12 to 2014-07-19	0.975903
2014-07-20 to 2014-07-27	1.05273
2014-07-28 to 2014-08-04	1.00774
2014-08-05 to 2014-08-12	1.05054
2014-08-13 to 2014-08-20	1.03416
2014-08-21 to 2014-08-28	0.972597
2014-08-29 to 2014-09-05	0.955384
2014-09-06 to 2014-09-13	0.950521



Daily crop ET (basal)



Polygon tool



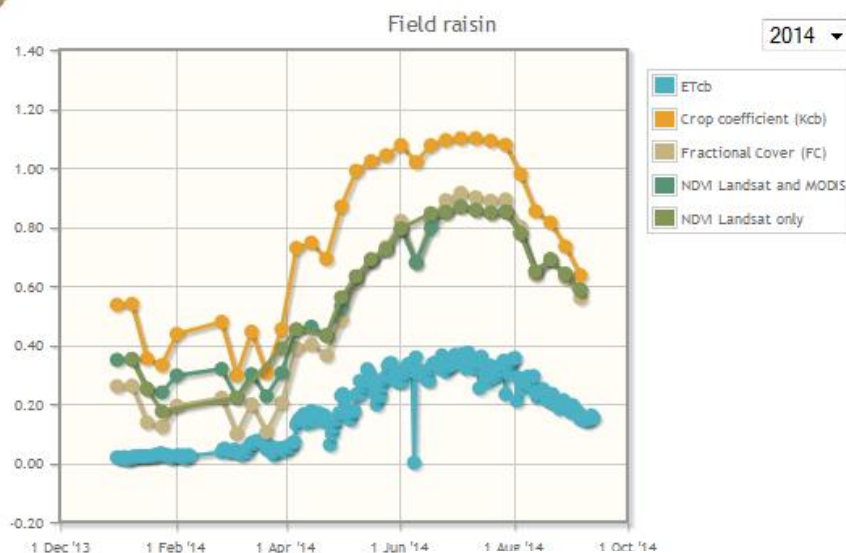
Welcome Lee Johnson.
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Go to: [five points, ca](#)

Search

[About](#) [Help](#)

Select Date: 2011-07-04



Field info

[Download 2014 data](#)

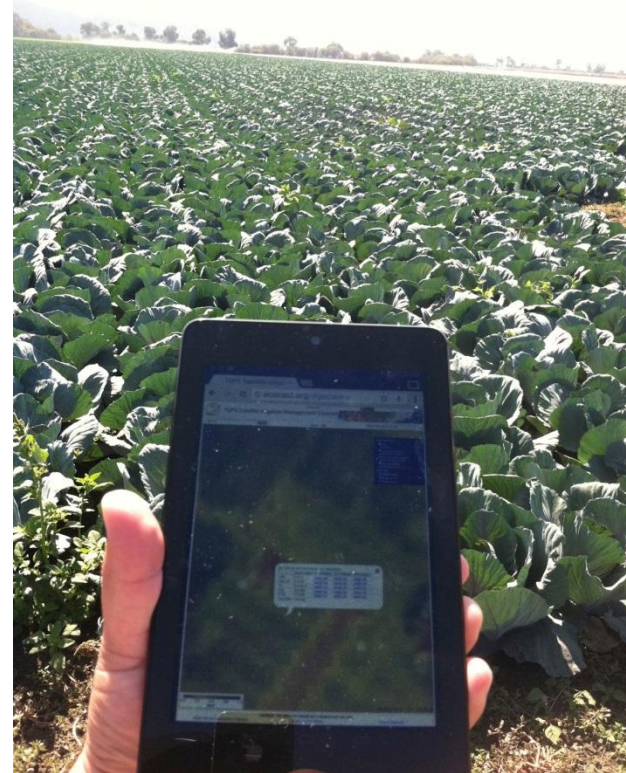
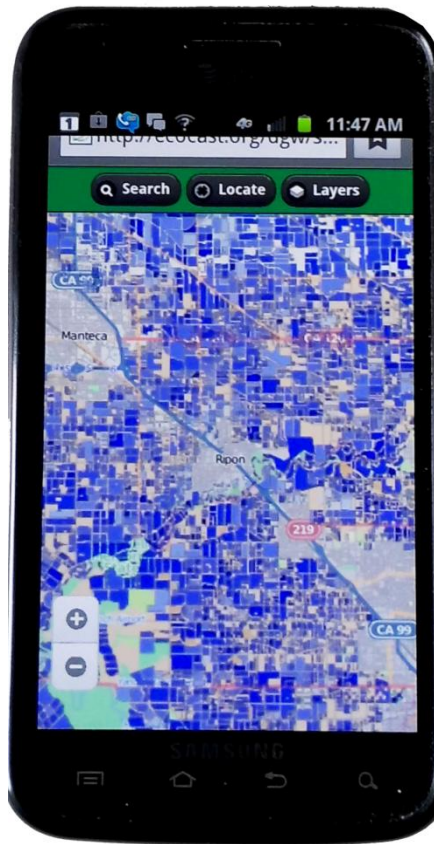
- ## SIMS Data Layers

- ☐ ETcb
2011-07-04
- ☐ Crop coefficient (Kcb)
2011-07-04 to 2011-07-11
- ☐ Fractional Cover (FC)
2011-07-04 to 2011-07-11
- ☐ NDVI Landsat and MODIS
2011-07-04 to 2011-07-11
- ☐ NDVI Landsat only
2011-07-04 to 2011-07-11

Base Layer

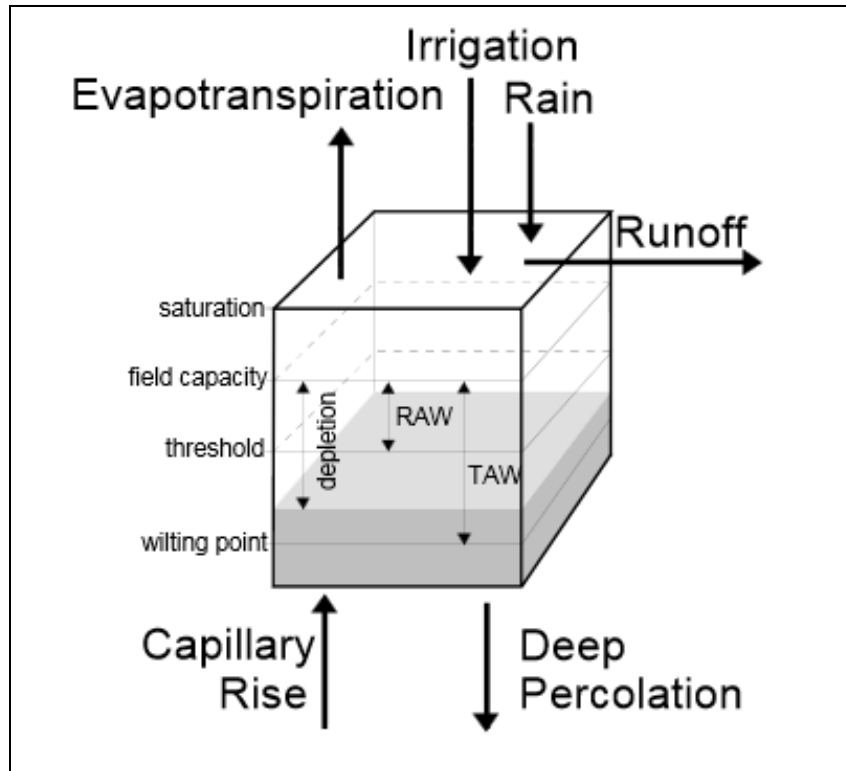
- ☒ Google Satellite
- ☐ Google Physical
- ☐ Google Streets

Mobile-optimized interface under development



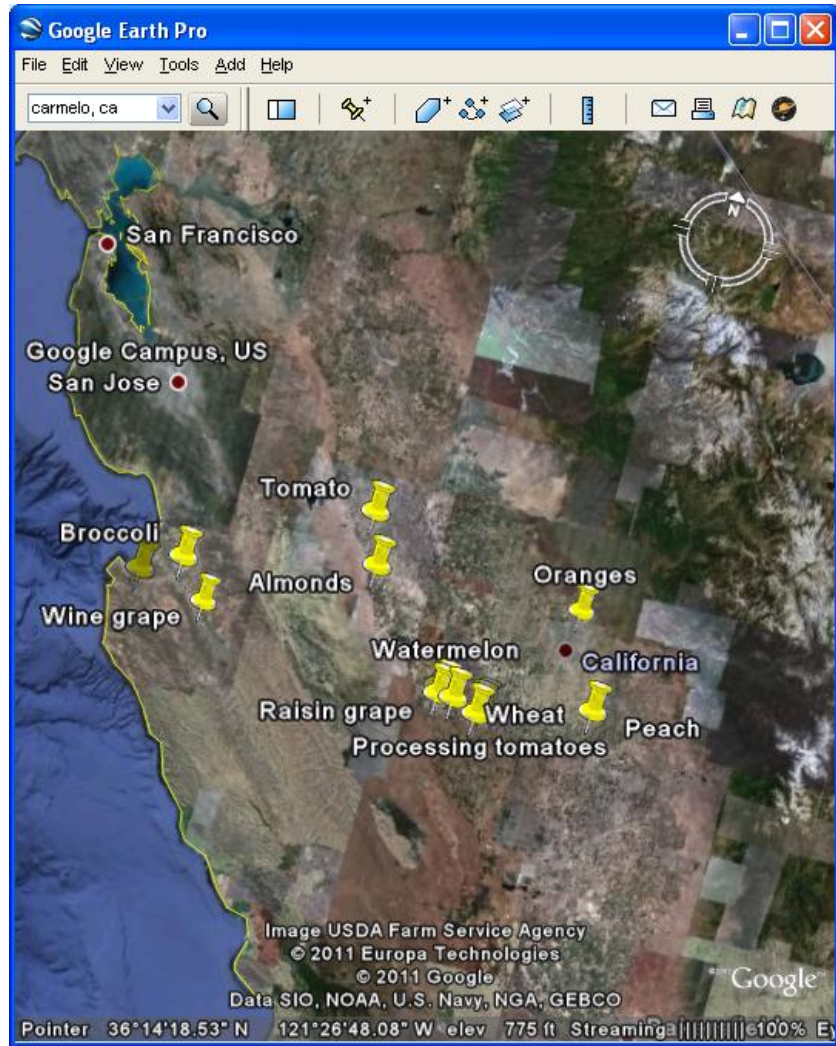
Calculation of Ks and Ke

Soil water balance model:



- Requires some add'l info:
 - irrigation schedule
 - delivery method
 - soil texture
 - crop type
- Derive stress & evaporation coeff's: Ks, Ke
- Calculate adjusted ET as:
$$ETc\ adj = (Ks * Kcb + Ke) * ET_o$$

SIMS evaluation



Monitor *seasonal* ET by soil water balance:

$$ET = P + I - D - \Delta S$$

P = precip, I = irrigation

D = drainage below root zone

ΔS = change in soil water content



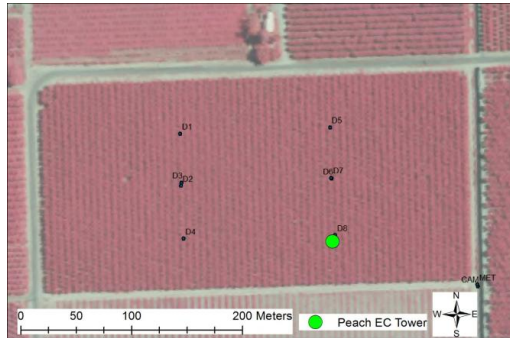
Seasonal ET

~10-15% error vs. ground measurements of seasonal ET for several crops:

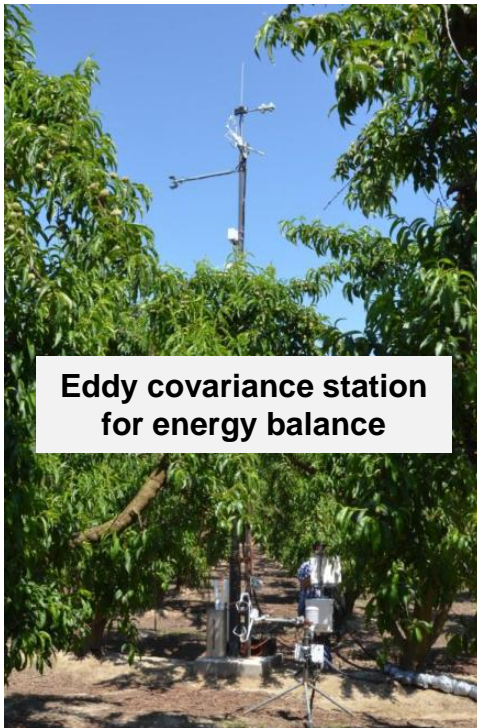
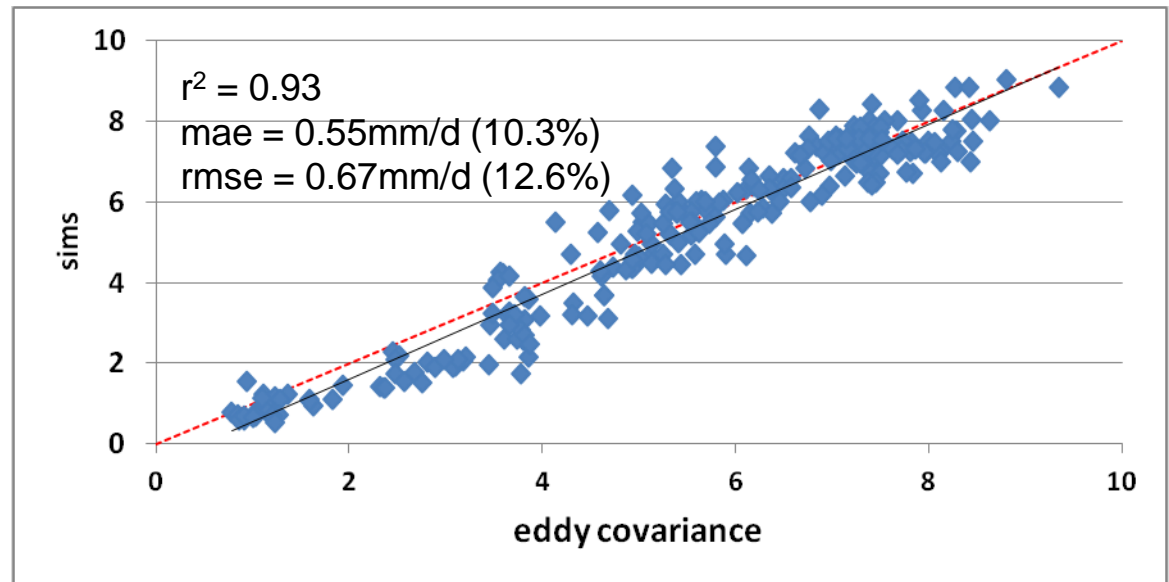
Almond
Garlic
Lettuce
Melon
Peach
Tomato
Wheat
Cotton*
Grape (raisin)*
Grape (wine)*
Orange*

**after post-processing with soil water balance model*

Daily ET



Daily ET_c (mm) for SJV peach orchard, 4/6/2012-12/3/2012



Field data courtesy Dr. Ray Anderson, USDA/ARS

Example applications

- ET-based irrigation scheduling
- Calculation of agricultural water use fractions
- Fallowed area mapping

Summary

- Background, concepts
- Remote sensing of ET (SIMS example)

Applications:

- ET-based irrigation
- Water use fractions
- Fallowed area mapping

Acknowledgments: F. Melton, K. Post, A. Guzman, J. Shupe, C. Lund, C. Roosevelt

Sponsors: NASA Earth Sci, USDA/CDFA-SCBGP, Cal DWR, CSU-ARI